TITLE: A Research Framework for Command Centre Teams

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A research framework for command centre teams

Peter Christian Rasker & Wilfried Maria Post
TNO Human Factors
P.O. Box 23
3769 ZG Soesterberg
The Netherlands
Tel. +31 346 35 62 60
Fax. +31 346 35 39 77
Rasker@tm.tno.nl

SUMMARY

The effectiveness of a command centre largely depends on the effectiveness of the team that keeps it going. This paper describes a framework of five research methods to investigate command centre teams. These methods comprise modelling, observing, experimentation, design, and evaluation. *Modelling* implies breaking up a whole human-human-machine system into essential elements. It is an analysis resulting in a clear description of the system. *Observation* is needed to identify possible bottlenecks in the command centre. It yields insight in the composite set of factors that influence the effectiveness of the command centre team. Single factors can be investigated systematically by *experimentation* using a contrived experimental task. The knowledge that is gained by modelling, observation and experimentation can lead to the *design* of a new command centre team, or the redesign of current ones. Finally, any particular design may need an *evaluation* to determine how team performance is effected. The application of the framework is illustrated by a number of research projects.

KEYWORDS

Command centre, teams, research methods

1 INTRODUCTION

The ability of teams to work effectively is a prerequisite in a number of critical work environments, including military command centres, fire-fighting, aircraft cockpits, emergency medicine, and air traffic control. Such teams often have to perform in complex situations that are characterised by time pressure, heavy workload, ambiguous information presentation and a constantly changing environment. High stakes are involved and poor performance may lead to considerable consequences.

Many studies demonstrate the importance of teamwork. For example, in the aviation domain several studies have shown that many incidents and accidents are due to miscommunication of the flight crew (Helmreich & Foushee, 1993). The accident with the *USS Vincennes* has been attributed to ineffective teamwork (Klein, 1993). Heath & Luff (1992) show that effective crisis management in the London underground line control room depends on how operators exchange and monitor information. Finally, in the medical world, ineffective teamwork has led to a considerable number of incidents in anaesthesia (Howard, Gaba, Fish, Yang, & Sarnquist, 1992) These studies show the importance of investigating teamwork to identify the factors that makes a team effective.

The focus of this paper is the research on command centre teams. A command centre team is defined as a set of at least two people that work together toward a common goal, who have been assigned to specific roles or tasks to be performed, and where the completion of the mission requires dependency among team members (Dyer, 1984; Salas, Dickinson, Converse & Tannenbaum, 1992). Central in our approach is that the command centre is viewed as a complex cognitive system in the sense that it takes situation specific information, knowledge from training and experience, mental constructs (hypotheses and assumptions), and norms and values that are combined into new information entities (Essens, Post, Rasker, 2000). The core-business of a team in the command centre is information. Signals, datalinks, intelligence and so forth must be received, interpreted, and assessed in order to decide upon the righteous action. Because tasks, information sources, and expertise is assigned to different team members, interdependent interaction is needed. This interdependency requires team members to engage in teamwork behaviours such as communication and co-ordination. The challenge is to determine how effective teamwork can be realised in complex systems such as the command centre.

The appreciation that teamwork must be seriously studied is shown by the variety of research questions that come from practice. A first type of question is related to the complexity of a command centre representing a need for a clear description and understanding of this human-human-machine system. Questions such as, "which tasks are performed and which knowledge is needed" and "what is the information flow in the command centre and how is this exchanged by team members" represent this need. A second type of question arises out of problems that are experienced in practice. Often there is a vague idea that something is wrong, but one cannot lay hold on the specific bottlenecks and the seriousness of

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bottlenecks. This is represented by questions such as "are there problems with the workload?" or "do we train our personnel well enough?". A third type of question comes from a need to develop a deeper understanding in the underlying factors. Questions such as "which type of knowledge is needed to communicate efficiently" or "what is the effect of cross-training on co-ordination" represent this need. A forth type of question is associated with the design of new concepts, systems or layouts. This is represented by questions such as "how must the command centre be equipped" and "what is the best layout of the command centre to support effective human-human interaction". Finally, the last type of question arises from a need to evaluate whether the designed concepts, systems and layouts are applicable and effective in the real world.

The objective of this paper is to describe in a framework how several research methods can be applied to investigate command centre teams. These methods are used to find answers for the various types of questions stated above. With these methods, teamwork can be investigated in command centres as well as in any other complex human-human-machine system. We will illustrate the framework with a number of research *projects* and research *techniques*. First the framework as a whole is explained, and then each method is discussed separately.

2 RESEARCH FRAMEWORK

For investigating team effectiveness in complex systems we describe a research framework consisting of five complementary, but individually applicable, methods that span all phases of team research and development. The five methods are modelling, observation, experimentation, design, and evaluation. Figure 1 presents this research framework.

Modelling is needed for gaining understanding of the complex environment in which the team has to operate. Modelling yields a description of the essentials of a team, such as its *structure*, the links with the broader *organisation* in which the team has to operate, the *functions* that has to be fulfilled, the tasks that the team members have to carry out, the *knowledge* they need for that, and the types of *information* that flows within the team. The resulting team model provides the set of descriptors for all team entities that are subject of further team research and development. Once the team is well enough understood, one is able to make a useful observation of an operating team. *Observation* deals with the actual team process, revealing a problem description in terms of possible *bottlenecks* and *challenges* for improvements. During observations, many facets play a role at the same time, and linking a problem to (*interaction* of) particular *factor* is not always possible. With experimentation, where a team environment can be controlled, the contribution of separate factors for team effectiveness can be identified. New initiatives, or observed bottlenecks and challenges in an existing team lead to team (re)design. Design encompasses the application of all factors of team effectiveness (known from own research as well as others) to new *concepts* and detailed *realisations*. Finally, a designed team may be evaluated to acquire objective team performance measures in terms of *speed*, *workload*, *quality*, and *quantity*.

Each method has a set of research and development techniques associated to it. The next sections describe de application of each method in several projects, and how they are supported by the available techniques.

3 MODELLING

The functioning of a command centre team is not easy to understand. For an outsider it probably seems like magic

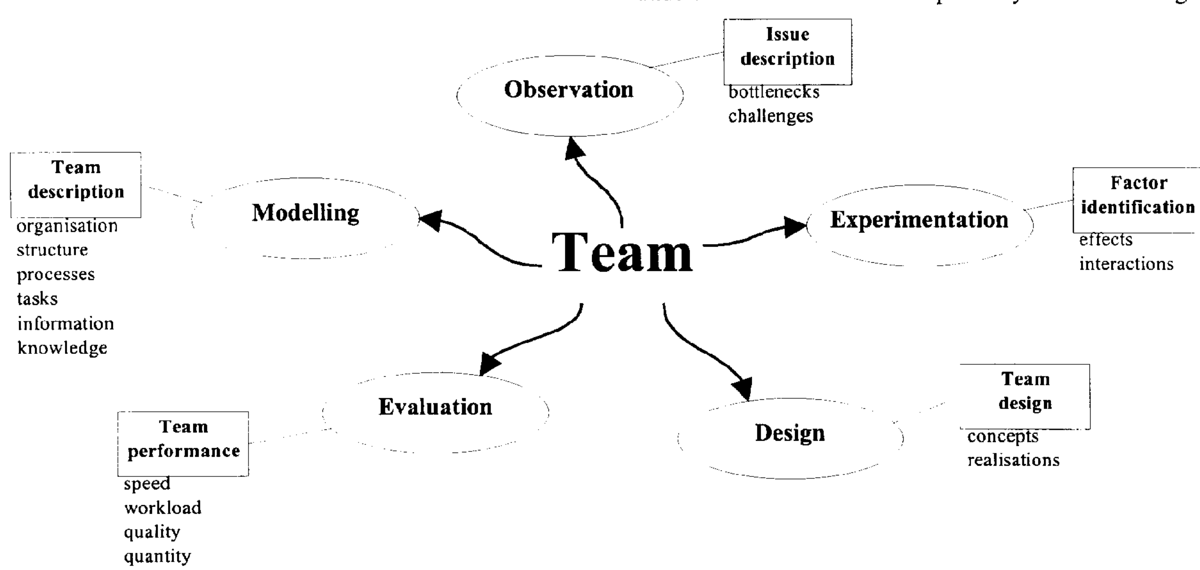

Figure 1: Research framework for team research and development

how a team does its job, using an overwhelming amount of displays, push buttons and communication equipment, communicate with strange abbreviations, being quiet at one time, and completely occupied the next moment. The purpose of modelling is to develop an understanding of this complex team and its environment. This is done by reducing its complexity through an analysis and description process. By analysis, the whole system is broken up into its essentials. This is a complex process itself, because the essentials and their relationships are not readily given. Often, they have to be abstracted from the many details, and the abstract entities that arise need to be labelled and described. By doing so, modelling provides a clear *team description* and an easily accessible "map" of the command centre team.

There are many ways to model a team. In our approach we distinguish nine so-called team modelling perspectives (Essens et al., 2000). These are an organisational model, a function model, an information model, a function-information model, a human agent model, a technical means model, a knowledge model, a task model, and an event handling model (See figure 2). The organisation model shows the relation of the team within the broader organisation. The function model shows the command centre functions hierarchically. The information model shows the information that is used and processed in the command centre hierarchically. The function-information model shows the information dependencies of the functions on the different hierarchical levels. The agent model describes the team member roles; the technical means model the equipment that team members have to their disposal. The task model takes the end nodes of the functional hierarchy and couples these with the end nodes of the information hierarchy (as input and output), the technical means, agents, and the knowledge entities as controls. Finally, the event-handling model shows the response to a tactical event in a temporal sequence of functions that are distributed over agents.

By using a hierarchical approach in modelling, we are able to finish at any hierarchical level and still have a complete description. If necessary, specific end nodes of the hierarchy can be modelled in more detail when bottlenecks are experienced (or established by observation) in that part of the hierarchy.

Project

This method is applied to model the command centre of the Royal Netherlands Navy (RNLN) multipurpose frigate. Knowledge about the task-related structure was elicited from domain experts during group sessions. This forced the researchers to specify precisely their understanding of the system. The large quantity of information (changes, annotations, new branches) elicited in the group sessions was difficult to process afterwards. Because the models are strongly interrelated, adapting them became a major effort. For future modelling efforts, further technical support is needed for consistency checking, glossary update, version management, and for having navigational overview within and between models. Overall, this provided us with approximately 400 interrelated graphical representations implemented with a browser on CD-ROM.

Techniques

The first technique applied in modelling is *document analysis*. We gathered various documents, built a glossary of the terminology found, and, after having studied the material, we started with representing our own mental model of the human-human system. Next, we developed a *visualisation* technique to describe this mental model, first for communication among the researchers. We used a representation language and graphics in the models consisting of a restricted set of descriptors with a consistent form and a consistent meaning. For example, in figure 3, an arrow means data

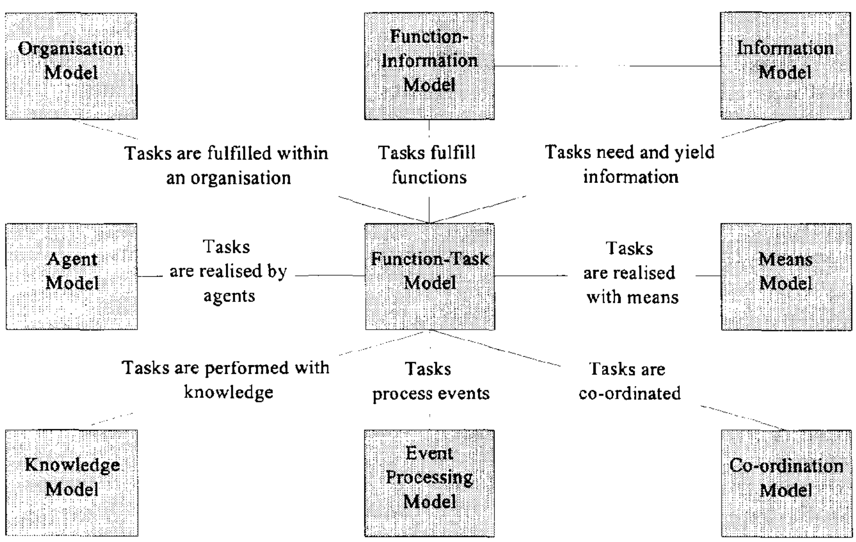

Figure 2: Suite of models for the description of a complex system

dependency, a small-circle with a line means a part-of relationship, a rounded box represents a function or task, a square box represents an information entity, and knowledge is represented by a square box with a line, After this preliminary description, we used the graphical model as a means for *interviewing* the domain experts. Because many subjective perspectives arose with the various experts we interviewed, we finally asked other, senior, experts, to give the models an official status, a technique we called *standardisation*.

4 OBSERVATION

Observations are needed to give an answer to the questions that arise out of problems that are experienced in practice, but were one cannot identify the specific *bottlenecks* or the seriousness of these bottlenecks. It concerns an *issue description* in order to develop insight in the *challenges* to improve team effectiveness. With observation we mean a systematic analysis and on-line measurements of the ongoing process of team

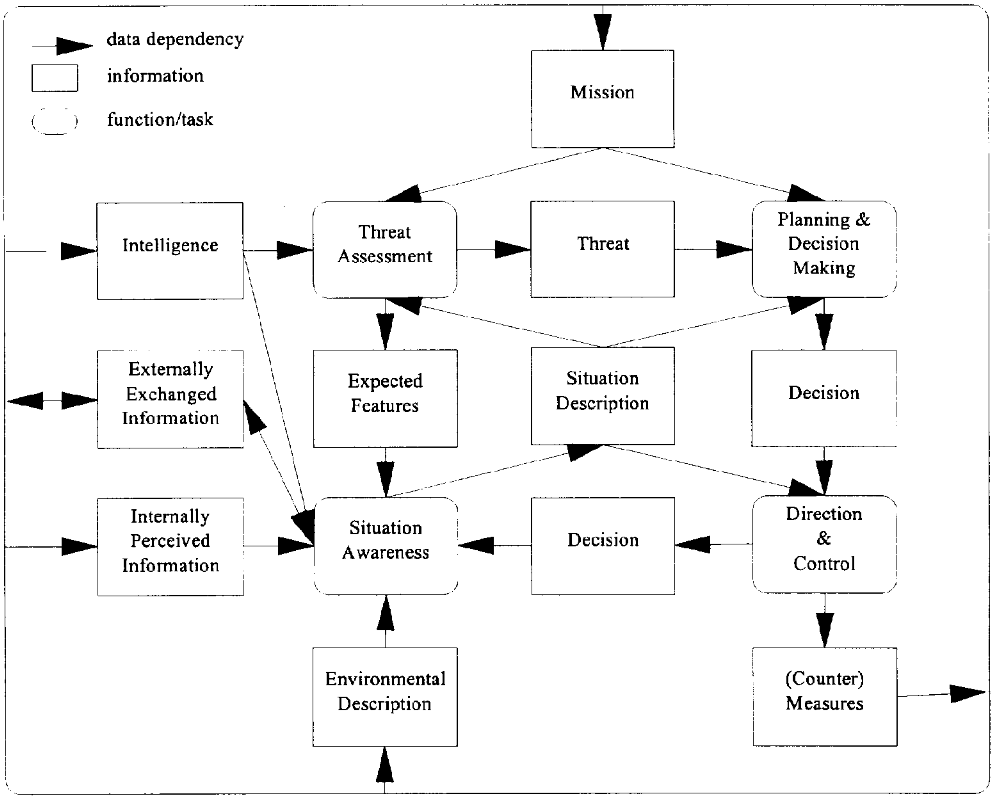

Figure 3: example of one level of the function-information model

Figure 3 shows an example of the used representation language for the function-information model. This example describes Command & Control at a generic level (Passenier & van Delft, 1997). The functions are linked with their information input and output entities. The diagram shows the data dependencies between the functions. *Situation awareness* consists of a permanent process of compilation, monitoring, and maintenance of the actual situation. Outside information and internally perceived information (i.e., from own sensors) is used to develop and maintain an actual situation description. This information is used for *threat assessment* by interpreting the current situation from a tactical perspective. *Planning & decision-making* is performed by selecting options and planning (counter)measures. The decision is executed during *direction & control* by giving directives and allocating resources.

functioning in its natural setting. This provide insights in the effectiveness of the command centre team and reveal possible bottlenecks concerning individual task performance, communications and information exchange, co-ordination, workload and so forth. This insight is needed to solve the experienced problems either by designing a new system or by adjusting the current system.

Project

Observations are performed to investigate the command centre of the RNLN multipurpose frigate (see, for an elaborate description, Essens, this volume). Four operational command centre teams performed three realistic warfare scenarios (e.g., *baseline* normal pressure, time pressure from handling multiple objects, uncertainty form object behaviours) in a simulated command centre trainer with a duration of three hours

including operational briefing at start shift. Seven domain experts strategically distributed over the team members' positions determined systematically the performance quality. During task execution each team member produced a workload score. A questionnaire completed data collection. In a debrief session a selection of the observations were discussed with the experts, the investigators, and team members to get more insight in the background of particular actions and decisions. Based on these observations it was concluded that in times of stress own task responsibilities dominate and push away teamwork responsibilities despite the generally strong emphasis on total team performance.

Techniques

To observe systematically, three techniques are developed to measure performance: a *quality indicator sheet*, a *workload registration tool*, and a *task-performance questionnaire*. In addition, task performance is registered digitally on video (including audio) that is used for reviewing.

After a pre-briefing about the content of the research, performance is measured during task execution. Domain experts (e.g., operational experienced officers) score the *quality indicator sheet*. Each time a problem is scored, the experts also push a button that results in a time registration linked to the video stream. This is used during the review to the find easily the video data that is linked to the scored problem. Workload is measured with the *workload registration tool*. This specially designed button panel consists of five buttons. The buttons correspondent with a five point scale that each measures a degree of subjective workload. The registration of the subjective workload takes place every five minutes. The button panels are linked to the video stream that registers the measurements.

Afterwards, the team members fill in the *task-performance questionnaire*. In the meantime, the domain experts and the researchers review and discuss the task performance based on the scores on the *quality indicator sheet*. During this review it is determined which observed problems are the most critical and need to be made more explicit. Subsequently, the domain experts, the researchers, and the team members discuss these problems to develop a deeper understanding of the underlying causes. When needed, the video data are showed to explicate. All together the experts' scores, the workload measures, the questionnaires, and the discussion reports form the data from which conclusions about the observed problems are drawn.

5 EXPERIMENTATION

Observation yields insight in the composite set of factors that influence the effectiveness of the command centre team. From observations, however, it is not clear to what extent single factors may affect team effectiveness. Therefore, we investigate single factors systematically by using a contrived experimental task in the form of a low fidelity simulator. With the help of such a task we attempt to *identify factors*, and develop an understanding of their *effects* and *interactions*. There are several advantages for using a low-fidelity simulation (see also, Bowers, Salas, Prince & Brannick, 1992). First, the methodology is available at relatively low cost. Second, it gives opportunities to develop the characteristics needed in team research. Third, it provides the requisite experimental control of independent variables. Finally, it is relatively simple to train team members, which makes it possible to invite naïve participants in stead of operational team members that are difficult to recruit.

Project

Experimentation is used to investigate the effect of intra team feedback on developing shared mental models in Command & Control teams (Rasker, Post & Schraagen, in press). Team members that share mental models, are expected to have common expectations of the task and the team, allowing them to predict the information needs of team members accurately. This makes it possible for team members to offer each other the necessary information at the right moment, which results in an improved performance. It is hypothesised that intra team feedback plays an important role in adjusting and developing a shared mental model. By giving each other feedback, team members develop an understanding of each other's tasks that gives them insights in which and when information must be exchanged. A distinction is made between performance monitoring and team self-correction. Performance monitoring is the ability of team members to monitor each other's task execution and give feedback during task execution. Team self-correction is the process in which team members engage in evaluating their performance and determining their strategies after task execution. In two experiments, the opportunity to engage in performance monitoring respectively team self-correction was varied systematically. The results show that teams perform better when they have the opportunity to engage in intra team feedback. Both performance monitoring as well as team self-correction appeared to be beneficial for team performance.

Techniques

One complicated factor of studying teams using a low-fidelity simulator is that the generalizability to real-world environments is limited. We tried to reconcile this by developing an experimental team task that contains the activities, processes and situations that are typical for Command & Control teams. Based on a generic Command & Control model we performed a task analysis using the previously described modelling method that provides not only a task hierarchy but also describes the information dependency between tasks, the knowledge needed to perform tasks accurately, and the sequence of tasks for each team member. Based on this

task analysis we specified the different roles and expertise of team members and the information dependency between them. In addition, by showing that the specified tasks have to be performed in parallel, we demonstrated that the experimental task is a task for two team members, which cannot be performed individually. Based on the task analysis, we attempted to develop an experimental team task that contains the advantages of low fidelity simulations but still can be generalised to real-world environments.

The experimental task we developed is a low-fidelity simulation of a dispatch centre representing a fire-fighting organisation in a city (Rasker, Post & Schraagen, in press). The fire-fighting team, consisting of an *observer* and an *allocator*, is required to fight fires in order to keep the number of casualties as low as possible, which is the goal of the task. In order to accomplish the goal, the observer has to assess the city and inform the allocator about the status of the buildings. This is comparable to the situation assessment function in Command & Control. The allocator has to allocate a number of resources (i.e., fire-fighting units) to the buildings to extinguish fires. This is comparable to the function of decision-making and taking counter measures in Command & Control. Because the number of units is limited, the team must prioritise and decide upon which fires they want to extinguish. Team members are interdependent of each other. This means that they are required to interact continuously about the status of fires and the resources to accomplish the goal.

6 DESIGN

One part of the development of a new human-human-machine system, such as a new platform, is the design of certain team organisations such as for Command & Control, navigation, and ship control. *Team design* can be at a *conceptual* level (e.g., a proposed task organisation) or a can be a *realisation* at a detailed level (e.g., the layout of a command centre). A team organisation may be redesigned, when bottlenecks or challenges are observed in an existing team. In a design process, the known team factors are applied to new team concepts and actual working teams.

In designing a human-human system the following phases can be differentiated (Beevis, Essens and Schuffel, 1995):

- Defining the mission of the overall system
- Establishing the functions that need to be fulfilled
- Determining the tasks that need to be carried out
- Determining the required manning and means
- Job design (task allocation)
- Workplace design

Project

The design process is illustrated by the development of the command centre of the Air Defence and Command Frigate of the RNLN. The first phases of the design process were already established by the RNLN: the mission to establish the functions to fulfil the number of agents needed, the choice of equipment, and job design. Our role in the design team was to design the workplace (Post & Punte, 1997; Post & Punte, 1998).
From the literature and our own research, a number of factors for team effectiveness were identified:

- shared mental model (Cannon-Bowers, Salas & Converse, 1993)
- non-verbal communication (Fussel & Benimoff, 1995)
- adaptive co-ordination (Entin & Serfaty, 1999)
- situation awareness (Endsley, 1995)
- intra team feedback (Rasker et al., in press)
- team training (Salas et al., 1993)

From these factors, and the design decisions made by the RNLN in the earlier phases, two concepts on team support (as well as other aspects, such as technical and economical feasibility) were generated and assessed. Both concepts had a number of aspects in common that already were an improvement to the most recent command centre that was designed for the RNLN, such as the use of large screen displays for deliberation support, and a briefing room for training support. One concept was a traditional one, based on the most recent command centre that was designed: consoles placed in three rows, the middle one the command row, the row in front the picture compilation and weapon employment row, and the row in the back the support row (e.g., communication support, equipment support, network support). In the other concept, the traditional way was left and the rows were placed in a circle. We found that in a circle, the mean distance between team members was shortest.

The second rounded concept proved to be the best at the aspect of team support. For individual work conditions, however, the rounded concept was unacceptable due to adverse ship motion effects (Bittner & Guignard, 1985). Nonetheless, a number of principles for this concept were taken over. This led to the final conceptual design, with large screen displays and an integrated briefing room, that was optimised for frequent and critical interactions (i.e., putting those people near each other who need to work in closest co-operation). Further, visual deliberation and supervision lines at larger distances could be optimised by placing the individual work places nor in a row, neither in a circle, but in a kind of wave form.

The next step was to translate the conceptual design in a detailed design. At this stage, we made a full scale wooden mock up of both the individual work places and the complete command centre, and invited in total 75 future users to assess the design (among other aspects) on co-operation, deliberation and supervision support. Based on this finding the command centre was redesigned and approved for realisation.

Techniques

In designing the workplace, we used a number of techniques:
- link analysis
- drawings
- scenarios
- physical mock-ups

In RNLN example, we only designed the workplace of the command centre. Currently we are carrying out research for the RNLN future Command & Control, in which we also design reduced command centre teams, including team size, necessary means, and job design.

7 EVALUATION

The ultimate goal of modelling, observation, experimentation and design is improving the effectiveness of *team performance*. Evaluation stands for determining and verifying this effectiveness. Two types of measures are important for team effectiveness: process measures and outcome measures. Process measures refer to *speed* and *workload*, and outcome measures to *quality* and *quantity*.

Project

Evaluation is not only possible at a final stage, when a design has been realised. In the command centre example provided above, we used a wooden mock up for evaluation purposes, and had RNLN personnel perform a scenario. We asked them to fill in a questionnaire on team aspects. The questions were about the positioning of their co-workers, how the command team was able to deliberate, how supervisors could view their personnel from their positions, and how they could communicate non-verbally. We let them compare seven row configurations (such as a straight row, an indented row and a waved row) on the team aspects mentioned above. Moreover, we made this comparison for three different individual work places: one with a single screen, one with two 20" screen, and one with a primary 20" screen and a secondary 14" screen, making up 21 (7 times 3) configurations. We could find at statistical significance level how type of row and type of individual work place relate to team aspects. Figure 4 shows some of the configurations of rows.

Another evaluation example is obtained from the SmartStaff project (see, for an elaborate description, Post & Hamaker, this volume). The aim of this project is to find the best team support for the Task Group Staff. This staff is embarked on board of the Air Defence and Command Frigate, and has its own Staff room. In contrast to the command centre and the navigation bridge of this frigate, the RNLN had no clear vision on how to equip the staff room. Therefore, we took it as a research challenge to come up with a support concept for team planning, which is the main task of the Task Group Staff. The resulting concept, called Smartstaff, supports the team with:
- both individual and shared work spaces
- flow and storage of electronic information
- a common focus of attention
- concurrent idea generation

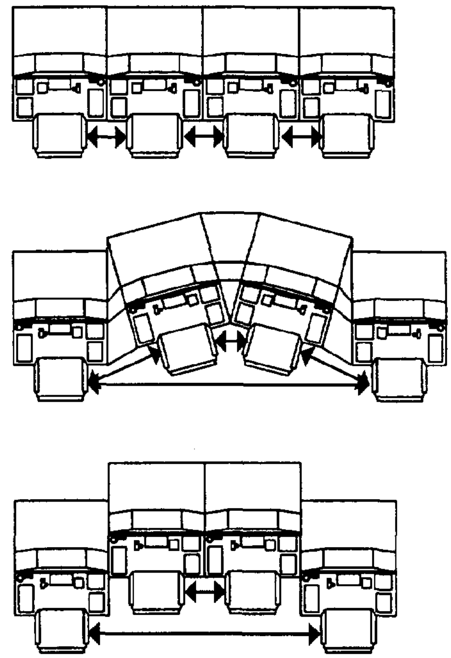

Figure 4: Configurations of rows. The arrows show some lines of views

SmartStaff has been evaluated by using a staff room mock-up with for each team member an individual workstation and two large interactive touch screen displays, electronic storage, retrieval and exchange of information, and an electronic idea pad: a tool for both individual and team generation and representation of ideas. To guarantee face-to-face contact and an unlimited view of the large screen display, the workstations were lowered and positioned in a semi-circle around the large screen display.

Our aim was to carry out a conceptual evaluation. At an early stage, we wanted to know whether our concept was profitable, without having to implement the concept fully. We were able to reduce the software development effort to a minimum, by using existing software as much as possible, and letting the integration efforts (often the most expensive parts of software development) over to the evaluators, who had therefore to strike some extra keys during the evaluation session.

In this evaluation session, all 14 RNLN Task Group Staff members, including the Commodore, served as subjects. They were first asked to fill in a questionnaire about their current staff room. Next, they had a one-hour

training in using the SmartStaff environment. Then, they were provided with a realistic scenario in which they had to plan a journey for the Task Group. After that, they had to fill in again a questionnaire, but now about SmartStaff. Having experienced this new task environment, the evaluation session concluded with a group discussion. During the session, an external observer, who joined the Staff earlier, assessed the team as well. It was found that SmartStaff provides better support on the unambiguity of the shared picture of a tactical situation and the plan itself, on time management, and on presenting and communications of ideas and plans. The quality of the plan was not influenced.

Techniques

Summarising, the techniques used in both studies are:

- hardware and software mock-ups
- Questionnaires
- Scenarios
- External assessor
- Experienced group discussion

8 SUMMARY & CONLUSIONS

Effective teamwork is a prerequisite in a complex system such as the command centre. Investigating teamwork and determining what makes a team effective is a great challenge for team researchers. The objective of this paper is to describe in a framework how several research methods can be applied to investigate command centre teams. This framework helps to place the questions that come from team practice in the set of methods and techniques that are currently available. The research framework that is proposed comprises five methods that cover all aspects of team research: modelling, observation, experimentation, design and evaluation. For each method, the research framework was illustrated with a number of projects and the techniques Table 1 gives an overview of the methods, matched with the questions for the specific projects, the used techniques, and the results.

Matching the questions to the methods makes it clear, in our opinion, which research effort is possible to provide usable answers. This serves as a guidance to make a choice between the methods available. Although the methods are treated separately, they are related with each other. Most important is that they all contribute to our knowledge of how teams perform and which factors make teams effective. This knowledge is used to modify and refine the research techniques and give direction in our new research efforts. Moreover, this knowledge is used to develop new concepts and realisations for optimising team effectiveness. We conclude that the research framework provides a useful overview of the methods one can apply to investigate command centre teams. Each method can be used to find an answer to a part of the puzzle how to optimise effective teamwork. In total, the research framework represents an integral approach for investigating command centres teams that should lead to an answer of the complete puzzle.

For future research concerning team effectiveness in the command centre, all methods will be applied. *Modelling* will be applied to describe the command centre of the new mine counter measure vessels of the RNLN. In addition, we are planning to elaborate our modelling techniques in order to simulate team behaviour in Command & Control situations. This way we are able to use modelling not only for description but also for *experimentation*. Different factors will be modelled in order to investigate their effects on team effectiveness. Furthermore, we will *design* a concept for improving the briefing sessions to achieve more effective communication in command centre teams. This design will also be *evaluated*. With this and other research efforts, we attempt to develop a new concept for future Command & Control that improves team effectiveness in the command centre.

	Modelling	**Observation**	**Experimentation**	**Design**	**Evaluation**
Project	Multipurpose frigate	Multipurpose frigate	Intra team feedback	Air Command & Defence frigate	Air Command & Defence frigate SmartStaff
Question	What is the information flow in the command centre?	How can the performance of the command centre be optimised?	What is the effect of intra team feedback on developing shared mental models?	What is the best layout of the command centre to support effective human-human interaction?	Does the design fulfil its' expected effectiveness?
Techniques	- document analyses - visualisation - interviewing - standardisation	- quality indicator sheet - workload registration tool - task performance questionnaire	Low fidelity simulator: *fire-fighting task*	- link analysis - drawings - scenarios - physical mock-ups	- hardware and software mock-ups - questionnaires - scenarios - external assessor - experienced group discussion
Result	clear description of the command centre with 400 interrelated graphical representations	individual task responsibilities dominate teamwork responsibilities	teams perform better when they have the opportunity to engage in intra team feedback	complete workplace layout supporting team effectiveness	- workplace layout mock-up - SmartStaff concept supporting collaborative decision-making and planning

Table 1: overview of the methods, projects, questions, techniques and results

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